Fugitive Hydrogen Emissions in a Future Hydrogen Economy

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Agenda

- Purpose of study
- Individual sector hydrogen emissions
  - Electrolysis
  - Gas networks
- Overall system-level hydrogen emissions
- Implications of emissions

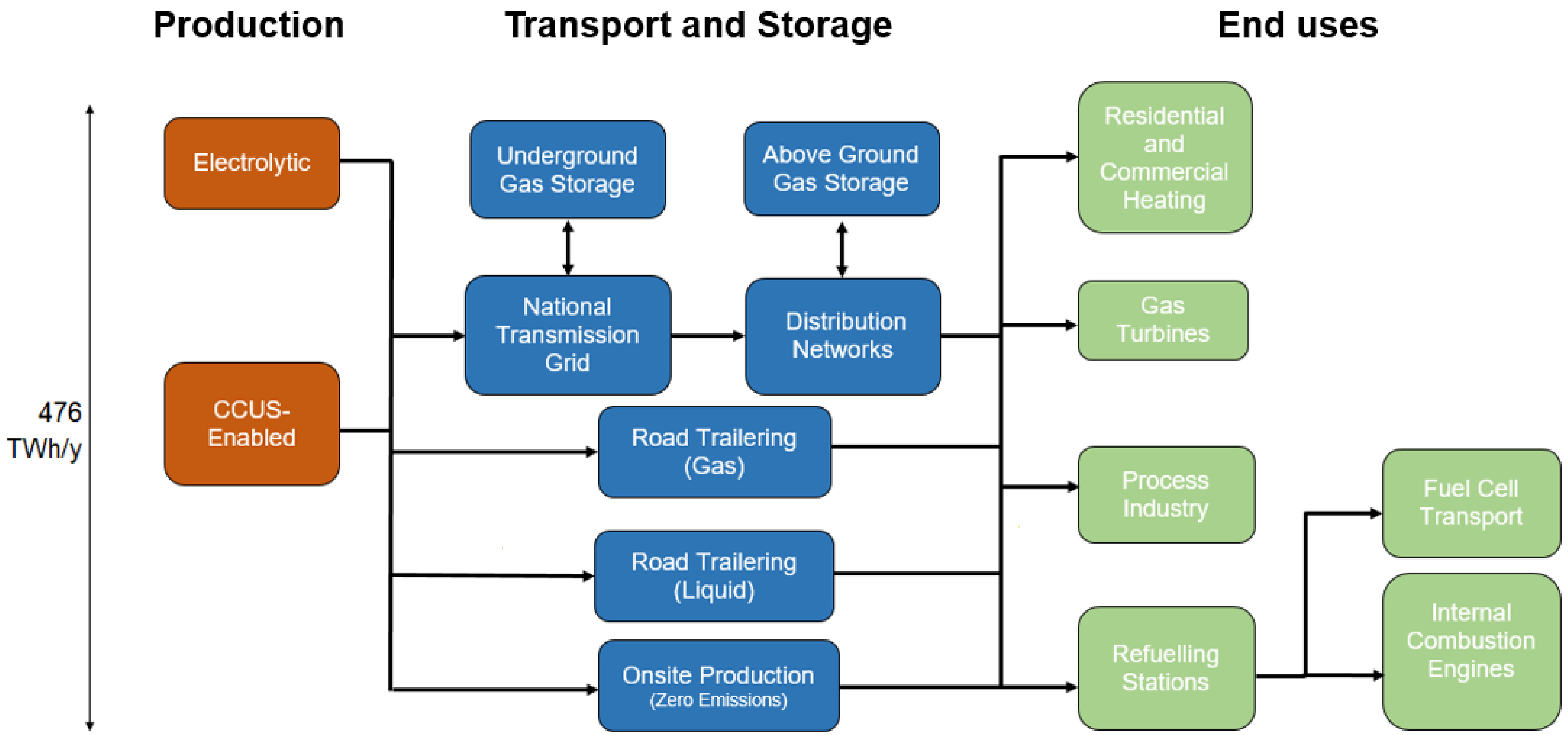
Purpose of Study

- To predict credible worst case emissions of hydrogen into the atmosphere in a 2050 hydrogen economy

- We have included:
  - Unintended leaks from joints, pipework and storage
  - Deliberate purging or venting either as part of a process (e.g. control valves in pipework) or for safety reasons

- We have not included:
  - Upstream carbon emissions
  - Hydrogen vectors such as ammonia or Liquid Organic Hydrogen Carriers that could emit hydrogen during their production or conversion processes

Central Scenario – National Grid's *System Transformation*



Electrolytic Hydrogen Production

- Leakage through casing and pipework
- Venting during start-up and shutdown
- Contamination of the vented oxygen (hydrogen crossover)
- Purging or bleeding processes during operation to remove impurities

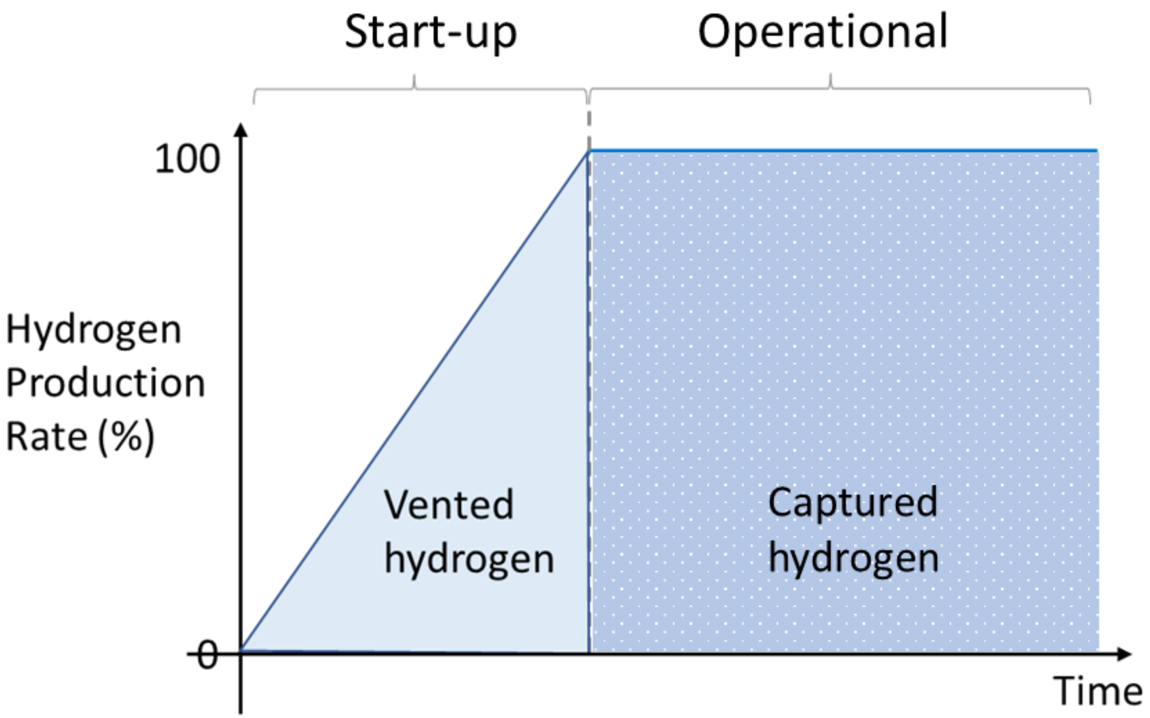
Venting at Start-up and Shutdown

- Electrolysers are vented at start-up and shutdown to remove moisture and explosive gas mixtures

- Venting lasts for 5-10 minutes

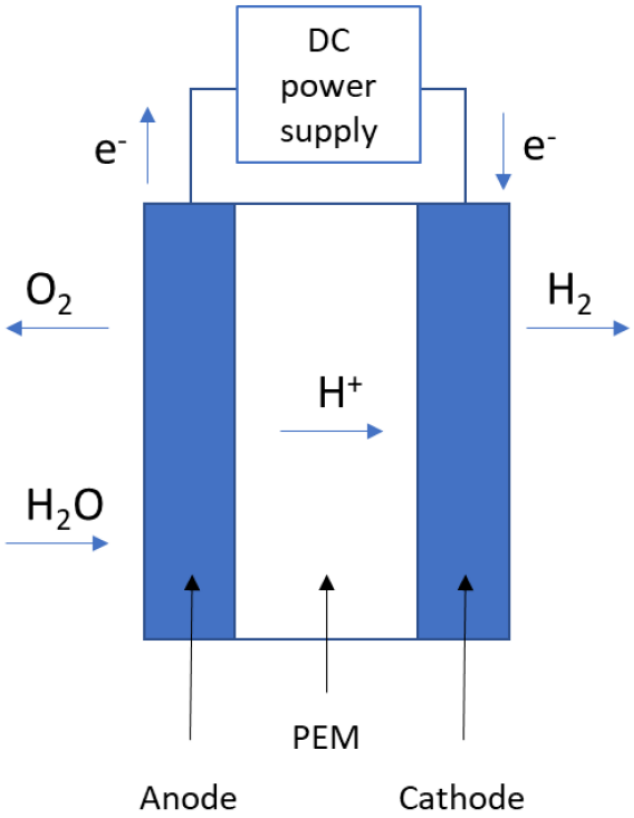
- These assumed to occur 50 – 300 times per year

- This suggests 0.05 – 0.6% of the total produced is vented



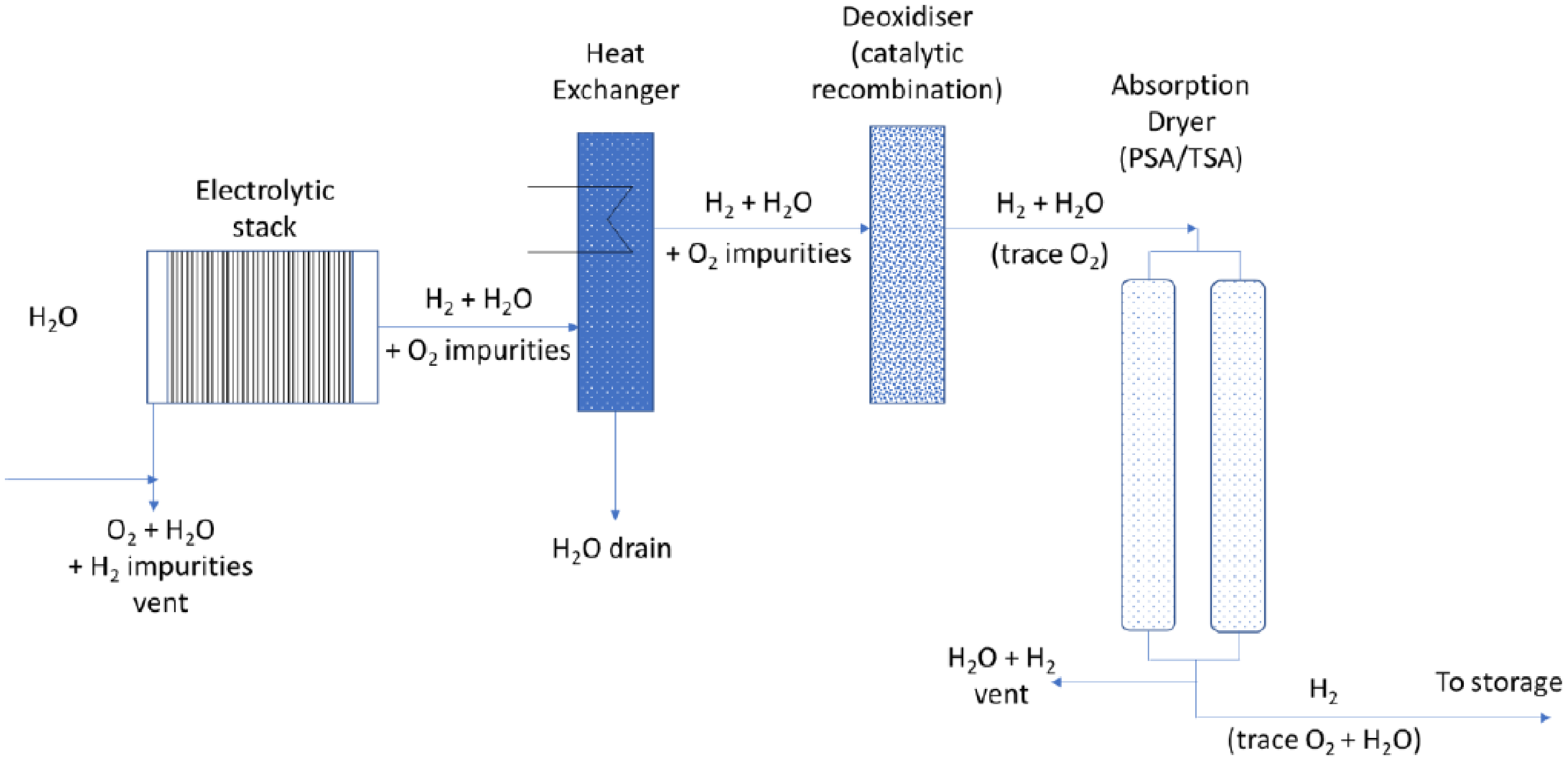
Hydrogen Cross-over

- During operation, hydrogen is produced at the cathode
- Some of the hydrogen gas produced crosses the membrane to the anode
- For safety, the concentration of hydrogen must be <1% at the anode
- Hydrogen cross-over is almost constant regardless of hydrogen production rate.
- Hydrogen emission depends on minimum production capacity and proportion recombined at anode
- Upper bound hydrogen release ~0.15%



Hydrogen Purging

- Hydrogen from electrolyser is purified to remove moisture and oxygen
- Absorption units are purged with hydrogen to release pollutants
- Hydrogen purging can be as high as 3 - 10%
- Hydrogen released could be recombined to produce water



Summary of Electrolytic Emissions

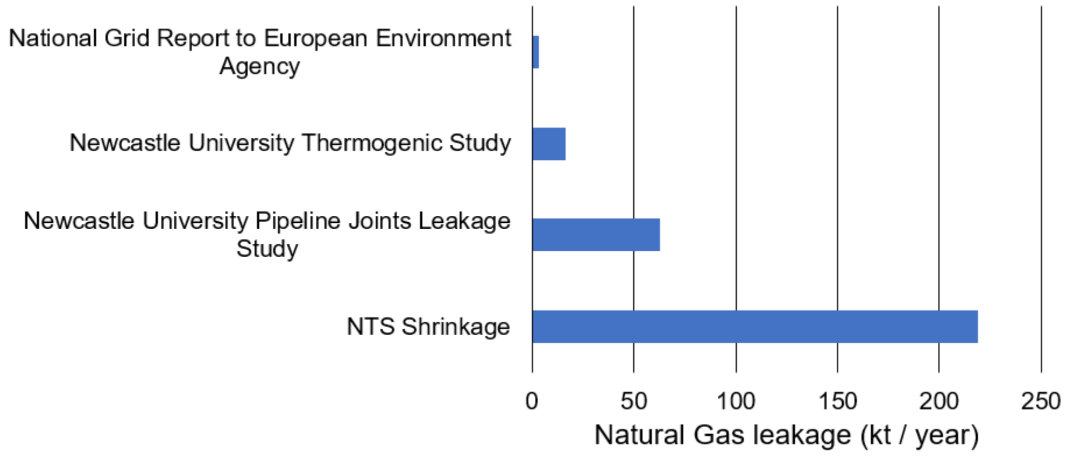
- Baseline emissions are:
  3.3% (50% confidence)
  9.2% (99% confidence)

- With catalytic recombination these could be reduced to:
  0.24% (50% confidence)
  0.52% (99% confidence)

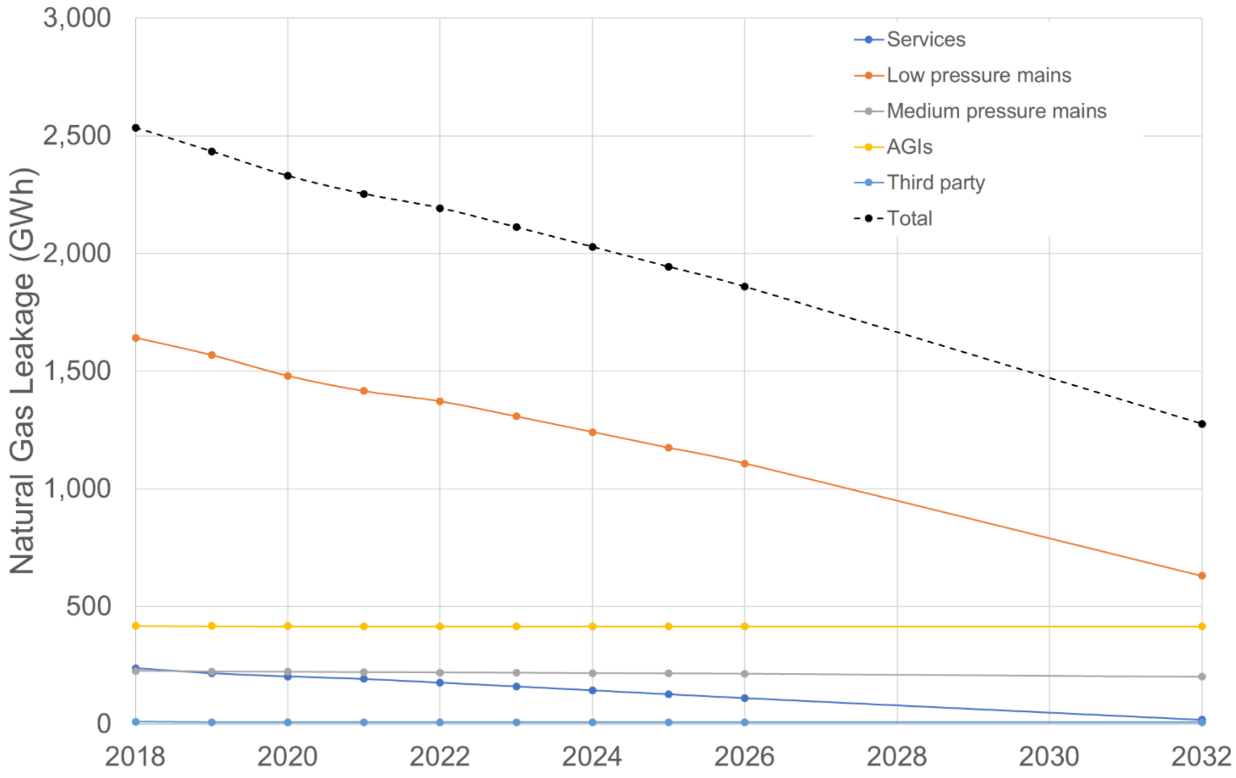
Emission Category	Hydrogen Release to Atmosphere as a Proportion of Hydrogen Produced	Factors that affect emissions predictions with ranges for model
Leakage through Casing and Pipework	n/a	n/a
Venting during start-up & shutdown	0.05 - 0.6 %	Duration of start-up/shutdown sequence [5 – 10 mins] Number of start-ups/ shutdowns [50 - 300 per year]
Venting of oxygen (hydrogen crossover)	0.05 - 0.15 %	Minimum production capacity: [10 – 30 %] Amount of hydrogen recombined to produce water [0 – 100 %]
Purging processes to remove impurities	0 – 10 %	Vented hydrogen during operation [3 – 10 %] Amount of hydrogen recombined to produce water [0 – 100 %]

Gas Network Hydrogen Emissions – Natural Gas

NTS



Gas Distribution Networks



Leakage Comparison – Laminar and Turbulent Flow

Laminar flow:

$$\frac{\dot{V}_{(hydrogen)}}{\dot{V}_{(natural\ gas)}} = \frac{\mu_{(natural\ gas)}}{\mu_{(hydrogen)}} = 1.2$$

$$\frac{\dot{m}_{(hydrogen)}}{\dot{m}_{(natural\ gas)}} = \frac{\rho_{(hydrogen)}}{\rho_{(natural\ gas)}} \frac{\mu_{(natural\ gas)}}{\mu_{(hydrogen)}} = 0.15$$

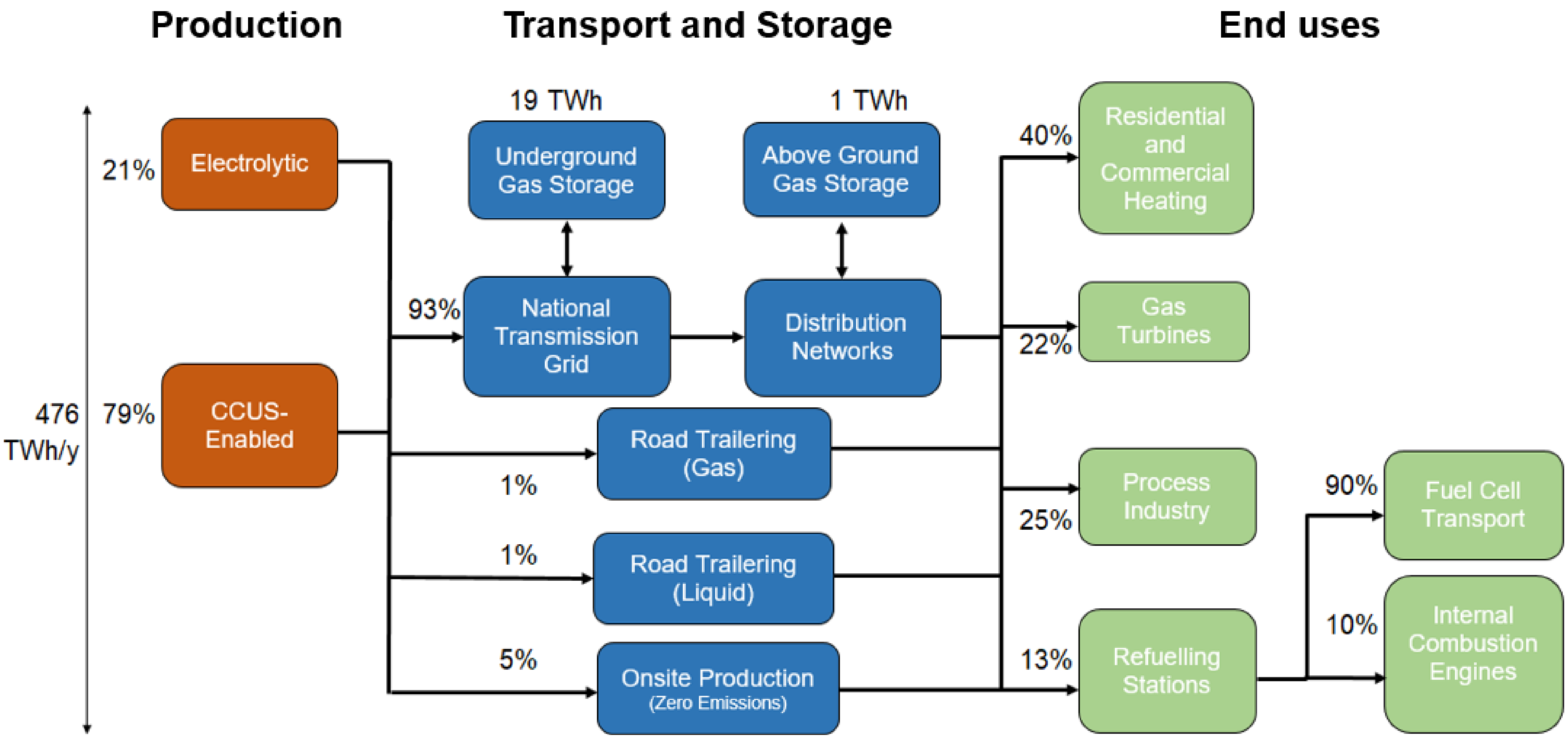
The conversion from natural gas leakage rates (either volume or mass flow rate) is almost a factor of three different for the two regimes

Turbulent flow:

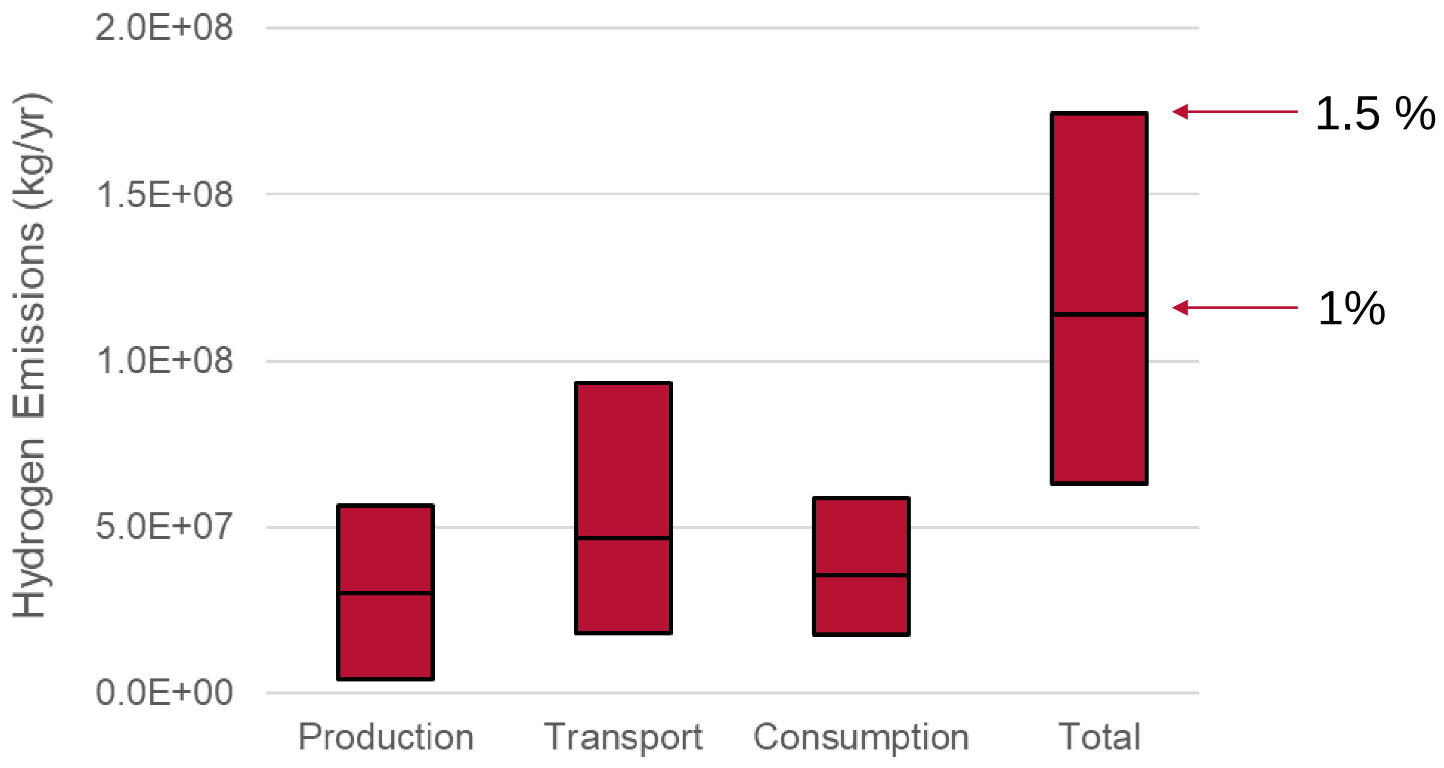
$$\frac{\dot{V}_{(hydrogen)}}{\dot{V}_{(natural\ gas)}} = \sqrt{\frac{\rho_{(natural\ gas)}}{\rho_{(hydrogen)}}} = 2.8$$

$$\frac{\dot{m}_{(hydrogen)}}{\dot{m}_{(natural\ gas)}} = \sqrt{\frac{\rho_{(hydrogen)}}{\rho_{(natural\ gas)}}} = 0.35$$

Central Scenario – National Grid's *System Transformation*

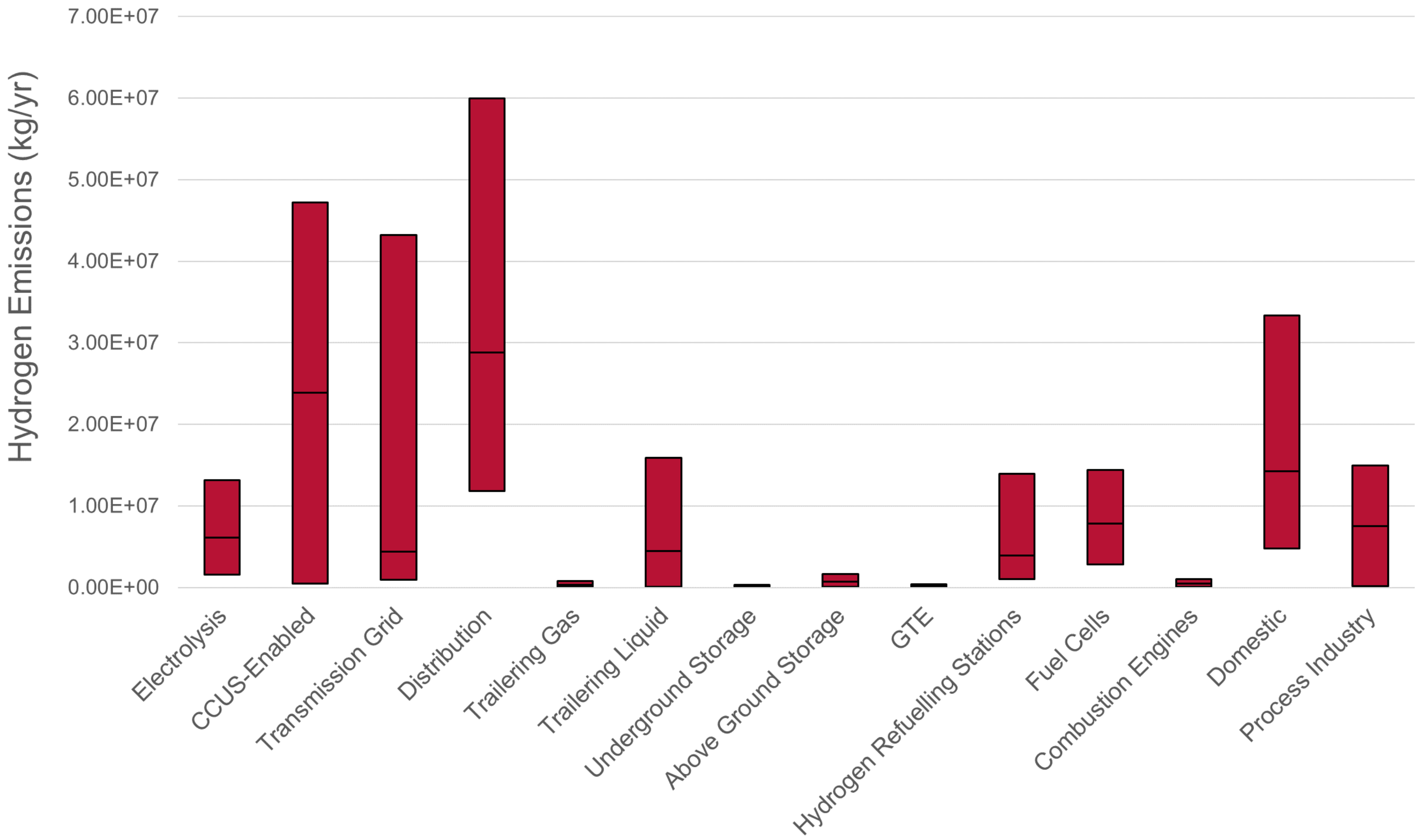


Overall Hydrogen Emissions



The bars represent the 1st, 50th and 99th percentiles (confidence levels)

Central Scenario – Impact of Individual Sectors



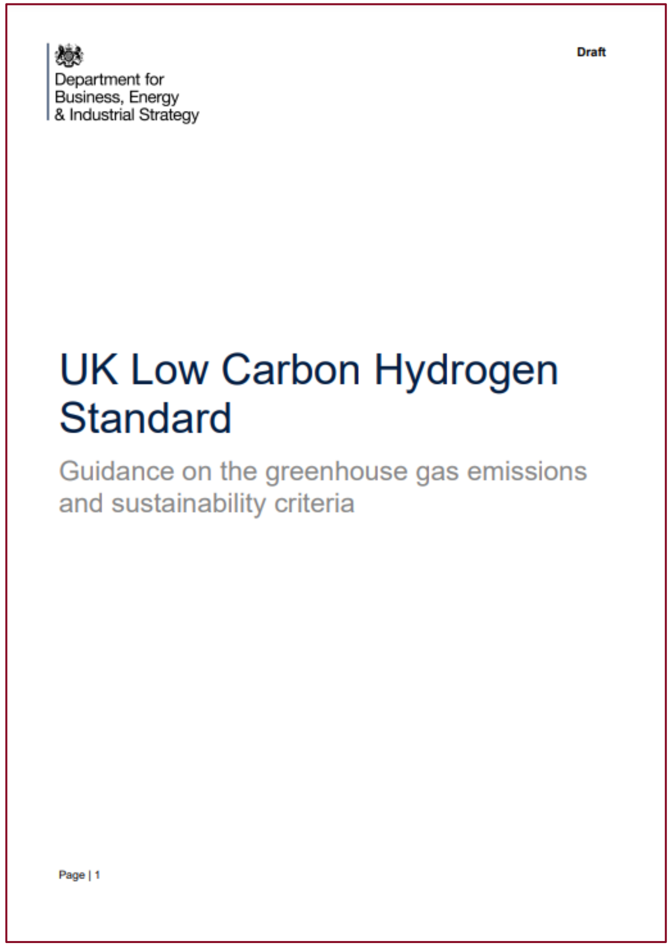
Implications of Study – BEIS Low Carbon Hydrogen Standard

For hydrogen production to be low carbon it must be < 20g CO2e / MJ (LHV)

At the moment, Fugitive Hydrogen Emissions are <u>not</u> directly included in the Standard. Hydrogen producers must:

- Produce a plan demonstrating how fugitive hydrogen emissions at the production plant shall be minimised.
- Provide estimates of expected rates of remaining fugitive hydrogen emissions by the plant.
- Prepare a monitoring methodology for fugitive hydrogen.

Fugitive Hydrogen Emission (%)	Mass CO_2e (g) /MJ hydrogen produced
0.24	0.22
3.3	3.0
9.2	8.4


Department for Business, Energy & Industrial Strategy

Draft

UK Low Carbon Hydrogen Standard

Guidance on the greenhouse gas emissions and sustainability criteria

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Implications of Study – Comparison to 6th Carbon Budget

In comparison to fossil fuels:

- Electricity production from natural gas:

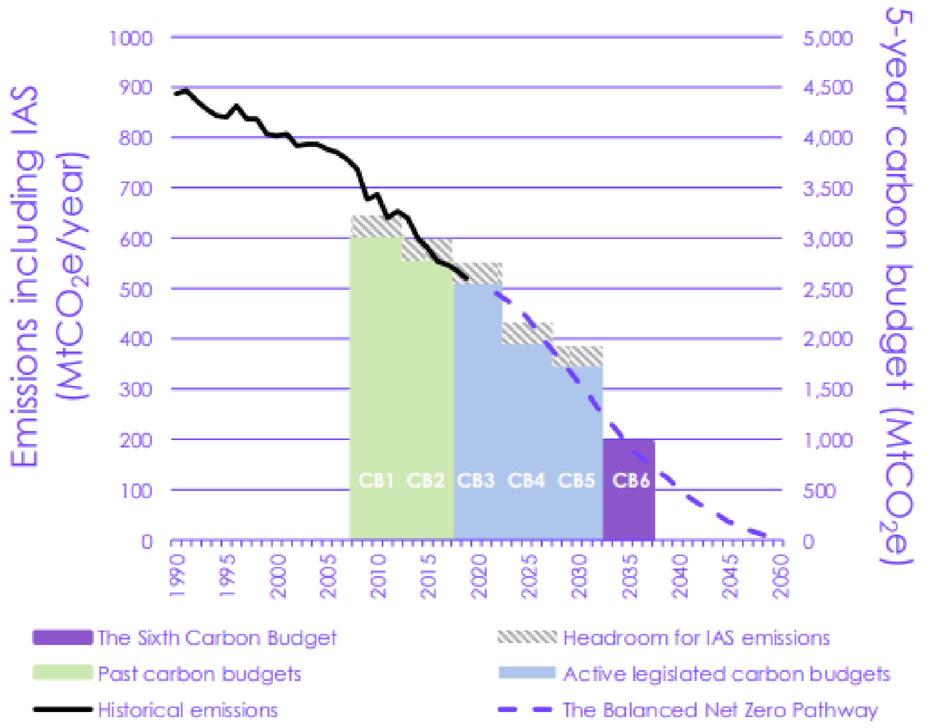
  380 tonnes CO_2/GWh electricity (**106 g CO_2 per MJ***)
- Electricity from coal:

  997 tonnes CO_2/GWh **(277 g CO_2 per MJ*)**

In comparison to the 6th Carbon Budget:

- 1% of 476 TWh hydrogen energy system is equivalent to 120 kt of hydrogen per year
- Based on a GWP of 11 this is **1.3 Mt CO_2e**

Figure 1 The recommended Sixth Carbon Budget



Source: BEIS (2020) *Provisional UK greenhouse gas emissions national statistics 2019*; CCC analysis
Notes: Emissions shown include emissions from international aviation and shipping (IAS) and on an AR5 basis, including peatlands. Adjustments for IAS emissions to carbon budgets 1-3 based on historical IAS emissions data; adjustments to carbon budgets 4-5 based on IAS emissions under the Balanced Net Zero Pathway.

*Dukes Energy Digest Version 5.14, 2021

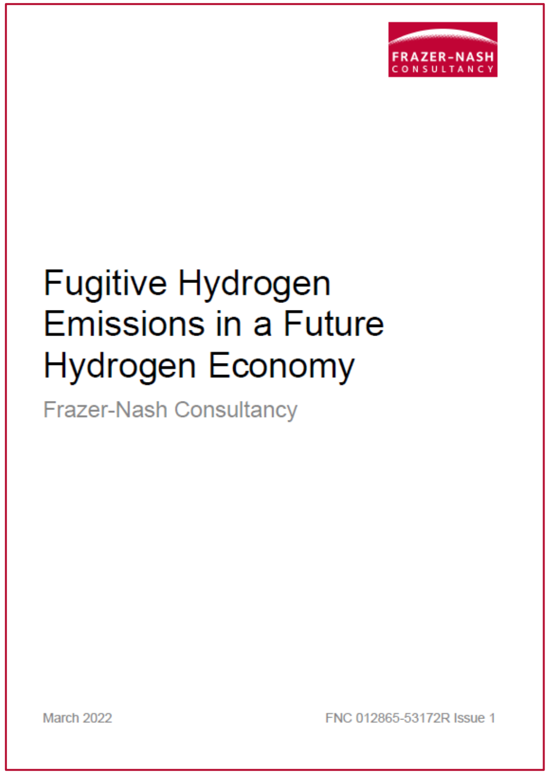
Conclusions

- Hydrogen emissions from electrolysis are currently significant but there are easy ways that these can be reduced which will become more viable as projects become larger.
- The single largest hydrogen emission is likely to be from the repurposed gas networks.
  - Undertake monitoring studies to improve the prediction of natural gas leakage from the NTS.
  - Undertake experimental studies to better understand the leakage flow regime (laminar or turbulent) within both the NTS and distribution networks.
- Emissions from compressed and liquid hydrogen are very significant as a proportion of the amount stored but their contribution to the overall system emission is very small.
- There are gaps in the evidence base…it has not so far been possible to predict hydrogen emissions from:
  - CCUS-enabled hydrogen production
  - Process industries and Manufacturing

Further Reading..

The full report has now been published on the BEIS Website:

https://www.gov.uk/government/publications/fugitive-hydrogen-emissions-in-a-future-hydrogen-economy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